Characterization of FS-3: A Detection System for Neutron-Photon Correlations in Fission

I. E. Hernandez, S. Marin, M. S. Okar, E. P. Sansevero, S. D. Clarke, and S A. Pozzi
Department of Nuclear Engineering and Radiological Sciences, University of Michigan, 48109
Sara Pozzi, pozzisa@umich.edu
Consortium for Monitoring, Technology, and Verification (MTV)

Introduction and Motivation

- Fission fragment emissions predicted by event generators have not yet been satisfactorily described
- System response produces large biases in experimental results, requiring careful characterization of system response and theoretical predictions
- By simulating the Fission Sphere (FS-3, Okar et al.) system, given correlated emission signatures, and comparing against experimental results, sensitivity may be deduced

Mission Relevance

- Fissionable material releases unique correlated signatures between neutron and photon observables
- Special Nuclear Material (SNM) is best characterized by these unique signatures
- By optimizing a detection system to specifically study correlations between fission observables, the accuracy of differentiation between SNM and regulated material may improve
- Simulations may guide the optimization and altering of the physical environment to suit detection of fission observables

Measurement System

- The FS-3 system comprises of 40 organic scintillation detectors
  - 30 stilbene crystals
  - 10 EJ-309
- It distinguishes particles using pulse shape discrimination (PSD), with a total absolute efficiency of 15% for neutrons and 2% for photons.
- Neutron energy is determined by time of flight

Technical Approach

- A series of scripts were required to conduct communication between event generators and transport codes
- This communication network (ppp_freya.sh) is now incorporated in the ARC-TS Great Lakes HPC Cluster and is available for department use
- The single bash command provides an easy and personalized interface for users
- The network allows users to adopt this simulation to any modeled system

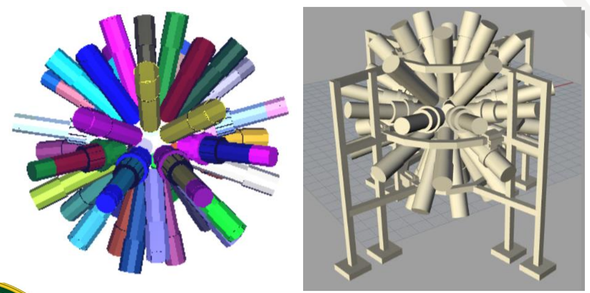

Fig. 1. (Left) MCNP visual rendering of 40 detectors (Right) CAD visualization of FS-3 environment

Source Description

- To verify the sensitivity of the experimental system, both correlated and uncorrelated simulations are constructed
- Few experimental data sets are available to validate experimental data and are currently limited to the ^{252}Cf spontaneous fission source
- Simulations were constructed using Fission Reaction Event Yield Algorithm (FREYA) to produce the correlated fission observables, and MCNP-PoliMi generator (IPOL) to produce uncorrelated data
- Events generated by FREYA and IPOL were then propagated onto a simulated model of the FS-3 system with MCNPX-PoliMi transport code (Figure 1)

Emission Characteristics

- A relationship between neutron and gamma-ray observables was investigated according to Multiplicity-Multiplicity and Energy-Multiplicity
- A negative correlation between multiplicity-multiplicity emissions in FREYA based of the conservation of energy (Figure 2) was predicted and verified
- A complex relationship between average neutron energy and neutron multiplicity was expected and observed (Figure 3)
  - This may be explained by initial fragment conditions and direct neutron competition

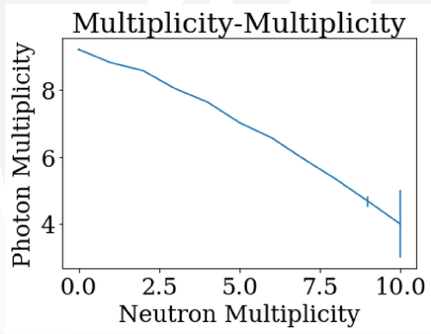

Fig. 2. Neutron and gamma ray multiplicity within a single fission event

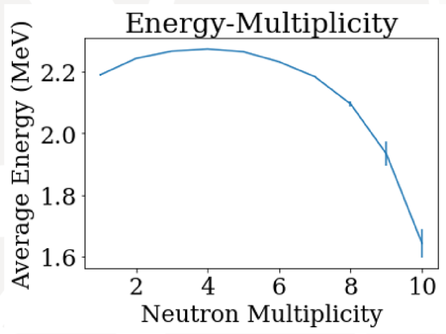

Fig. 3. Neutron multiplicity and average neutron energy within a single fission event

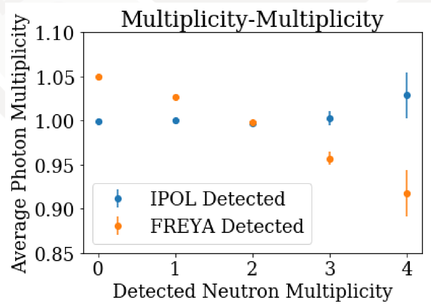

Fig. 4. Event-by-event detected neutron multiplicity and mean detected photon multiplicity

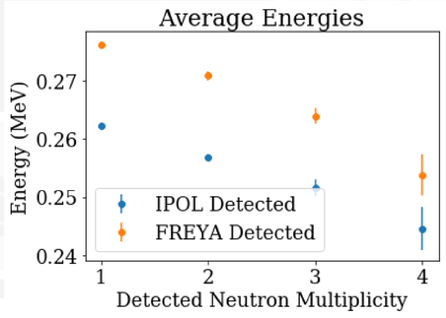

Fig. 5. Event-by-event detected neutron multiplicity and mean neutron energy

Results

- The simulated was conducted on FS-3 detector geometry in transport code
  - 50 iterations of 5e5 events by FREYA
  - 49 iterations of 5e5 events generated by IPOL
- Figures 4 and 5 focus on detected emissions seen by the FS-3 system
- Multiplicity-multiplicity correlations are largely negative in FREYA correlated results, but with some positive trend in IPOL uncorrelated results (Figure 4). The system response introduces positive multiplicity-multiplicity correlations
- For neutron multiplicity ≤4 in Multiplicity-Energy correlations (Figure 5), FREYA has shifted from positive to negative relationship as a result of system response

Conclusions

- A detection system was modeled to investigate the correlated signatures in the neutron-photon emission of ^{252}Cf(sf) and verify experimental results
- In both emission and detection, FREYA showed a negative multiplicity-multiplicity correlation
- There was no agreement between emission and detection between multiplicity and average neutron energy

Future Work

- Analysis of system response and its effects on detection capabilities within the FS-3 system
- Inclusion of data gathered by experimental FS-3 to compare detection results
- Use system response to unfold experimental data, determining the sensitivity of the Fission Sphere to fission emission correlations
- Analysis of Multiplicity-Variance relations to clarify complex multiplicity relationship
- Inclusion of angular multiplicity experimental and simulated data for analysis
- Estimation of FREYA error analysis, e.g. statistical and physics error

Impact

- The correlated nuclear data collected by FS-3 will improve capabilities of present and future non-proliferation technology
- The team will continue MTV fellow work with DNNG. Prepare of Los Alamos National Laboratory Engineering Undergraduate Internship Program within the ISR-1: Space Science and Applications Division

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